IOM3
The Institute of Materials, Minerals & Mining

Schools Affiliate Scheme

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Autumn Term 2008

NEWS

Autumn term again already?!

Hello! I hope you had a relaxing summer break. We certainly had a great time on our holiday, though with an 9 month old little boy that has recently learnt to crawl, I wouldn't describe it as very relaxing!

The past academic year was full of successes. Smart Materials, Smart Move, the Teachers' Day at Materials Congress, in May was very well attended, with 53 delegates from schools across the UK coming to find out about many different types of smart materials. You can read more about it on page 2 and the centre page pull out in this issue looks at piezoelectric materials, one of the topics covered at the conference.

The new SAS resource entitled Nitinol Bone Plate is now finished and after all the hard work we hope that you find it useful. If you would like to give us your feedback e-mail diane.aston@iom3.org.

The new term is looking busy for the whole Education Team. Anne and I will be visiting schools around the country giving materials talks and Toby will be out and about giving talks in geology lessons. He is also visiting a couple of schools that are thinking of setting up geology courses. If your school is considering this and you would like some advice then why not get in touch (toby.white@iom3.org). You can see where we will already be visiting on page 4, and find out how to book a visit.

I hope that you found the exam question analysis in the last issue useful. With the help of our Education Committee I have put together another page of information based on a recent question on page 9. If you have come across a materials, minerals or mining-related exam question that you would like us to explore at the next meeting, for inclusion in a future newsletter please post it in to the Doncaster address on the back of the newsletter.

Finally, in the Minerals and Mining pages Toby gives his reflections on his first year in his post.

I hope you have a great Autumn Term and look forward to seeing many of you on my travels.

This newsletter is written and edited by
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SMART MATERIALS – SMART MOVE, a great success!

On 14 May 53 delegates from all around the UK descended on Springfield House, the temporary home of the Institute in Grantham, for the third Teachers Day at Materials Congress. One long standing Schools Affiliate Scheme member even came over from Latvia!

Smart materials, Smart Move was a one day conference designed to provide the delegates, who were mainly teachers, with up to the minute information about many different types of smart materials. During the morning session presentations were given on Shape Memory Alloys, Piezoelectric Materials, Smart Packaging and Solar Power and the Glass Industry. I certainly learnt a great deal and plan to use some of the information I gathered in my future presentations. After lunch the final two technical presentations were on Smart Textiles and the Minerals behind the Materials. Toby White gave an excellent insight in to where the materials we all take for granted come from.

After the afternoon tea break Chris Baker ran an interactive session on co-operative learning in which the teachers explored techniques for using the information they had gained back in school and this proved very popular with those that had not had to rush off to catch trains!

One of the most popular aspects of the conference was a goody bag full of resources and samples relating to smart materials, some of which were from the presenters. All of the delegates said they would use the goodies back in school.

We are hoping to run a very similar conference again later in the Autumn Term at a different venue, so if you didn't get the chance to come along in May watch this space (and your post!) for details of future events.

Rolls-Royce Materials Master Class

Before the summer holidays I posted out information about the upcoming Rolls-Royce Materials Master Class. I thought it was worth printing a quick reminder about the course as there are still a few places left.

This excellent course is aimed at secondary science and technology teachers and is designed to bring your knowledge of materials up to date. The first part of the course, in the Materials Department at the University of Birmingham on 25 and 26 September, features lectures and lab classes on a wide variety of materials topics, from aerospace and magnetic materials, to smart materials, mechanical testing, structures of materials and microscopy. I will be attending on the first day to give a short presentation on careers in materials and attend the course dinner.

The second part of the course will take place a little later, on 14 October at the Rolls-Royce plant in Derby. This is a not-to-be-missed opportunity to visit the Company and look at the production build line where Trent 800 and Trent 900 engines are made. After lunch there will be a look at how engines are tested both non-destructively and to failure.

This course, which is supported by the Armourers and Brasiers' Company, is well worth attending and I would strongly recommend it to you and your colleagues. There is a small course fee of £30, which contributes towards the cost of food and accommodation. For more information contact Erica.Tyson@rolls-royce.com.

Autumn Open Day Programme

At the time of writing in late August, there are still a number of November Open Days still available to you and your students. These events are designed to bring to life the materials topics in A-level physics, chemistry and design technology, by giving you access to equipment that would not normally be available in schools. Typical activities include mechanical testing (tensile and impact testing), microscopy (optical and electron) and a talk on materials, though each department does something slightly different. The following dates are still available at a far-reaching range of venues.

University	Dates	Time	Max. group size
Leeds	12, 19, 26 November	1230 to 1600	24
London Metropolitan	07, 28 November	1000 to 1230 or 1400 to 1600	Not specified
Manchester	19, 26 November	1400 to 1600	Not specified
Newcastle	05, 12, 19, 26 November	1400 to 1600	30
Oxford	04	1000 to 1500	20
Queen Mary	13, 20, 27 November	1330 to 1600	30
Swansea	04, 18 November	1300 to 1600	12

The events are free of charge to attend you just need to get your students to the University.

If you would like more information about a particular event or you would like to make a booking please contact Dr Diane Aston by e-mailing diane.aston@iom3.org.

Schools Starpack Awards 2009

The Schools Starpack Awards 2009 is open for entries. Designed to encourage students to take up a career in the exciting world of consumer packaging design, the awards form part of IOP: The Packaging Society's Starpack Awards programme which also includes the Starpack Industry Awards, Student Starpack Awards and the Starpack Packaging Summit.

The Schools Awards are aimed at Key Stage 3, 4 and AS level, individual or joint activities depending on the brief chosen. Briefs for 2009 will include:

Charity Money Box - material to be used cartonboard
Emergency Shelter/Aid Pack – material to be used polythene
2012 Olympic Sports Drink Dispenser Pack – materials research brief

Brochures giving full details and guidance are now available – please email rosie.branston@iom3.org for a brochure. Website: www.starpack.uk.com

For further information please contact rachel.brooks@iom3.org.

Visit Diary

The Autumn Term is looking busy for the whole of the Education Team, with the three Education Co-ordinators out and about doing visits on most days. Your main point of contact if you would like information about any aspect of the Scheme, in particular visits and available dates is Anita Horton. Anita is based in the Doncaster Office and does a brilliant job of keeping us all in check! You can get in touch by calling 01302 380908 or e-mailing anita.horton@iom3.org.

These are the visits booked in to the diary so far this term. There are still dates available and we are already taking bookings for the Spring Term too. So get in touch and book us!

September		09	MacMillan Academy, Middlesborough	*04*	*Stewarts Melville Academy, Edinburgh*
04	Hull Trinity School	09	St Georges College of Technology, Sleaford	04	National Science Learning Centre, York
12	Northgate High School, Ipswich	13	Queen Ethelburgas College, nr York	06	St Clement Danes School, Chorleywood
12-14	ESTA Conference	13	Walthamstow Hall, Sevenoaks	06	Websters High School, Kirmuir
17	Saffron Walden County High School	14	St Marks School, Hounslow	07	Websters High School, Kirmuir
18	King Edward VI School, Southampton	14	St Edward's School, Oxford	11	Wellington College, Crowthorne
23	Queen Mary's College, Basingstoke	15	Kings of Wessex School, Cheddar	11	Clyst Vale Community College, nr Exeter
24	Geological Society, London	17	Ysgol Tre-gib, Llandeilo	12	Hymers College, Hull
25	Canon Slade School Bolton	21	Sir John Deane's College, Northwich	14	Materials Day for Schools at Sellafield
25	Rolls-Royce Masterclass	22	Marlborough College,	14	Queen Elizabeth Grammar School, Horncastle
26	Alsager School, nr Stoke	23	Dame Alice Owens School, Potters Bar	15	ASE Meeting, Bath
29	Peter Symonds College, Winchester	23	Northgate High School, Ipswich	18	Lady Lumley's School, Pickering
30	Peter Symonds College, Winchester	27	Ellon Academy, Aberdeenshire	19	Heckmondwike Grammar School
30	Meridian School, Royston	30	Lutterworth College	19-20	Clyst Vale Community College, nr Exeter
October		30	Grove Academy, Dundee	***December***	
01	The Sixth Form College, Farnborough	31	Mearns Academy, Laurencekirk	05	Kings College, Taunton
02	Blundell's School, Tiverton	31	Radley College, Oxford	12	Ditcham Park School, Petersfield
03	Colyton Grammar School, Devon	***November***		15	Bungay High School, Suffolk
06	Ivybridge College, Devon	03	Moulton School, nr Northampton		
07	Ampleforth College, nr Thirsk	03	St Georges School for Girls, Edinburgh		Diane Aston, Toby White, Anne Martyn

SMART CERAMICS

One of the presentations at Smart Materials – Smart Move, the Teachers' Day at Congress in May, that I found most fascinating was given by Dr Markys Cain from the National Physical Laboratory on Smart Ceramics. His presentation covered a number of different types of smart ceramics, how and why they work and where they are used. I certainly learnt something from his presentation, in particular how these often complex materials are used in everyday applications that we take for granted. In this article I hope to expand on some of the topics covered by Markys and I hope that you too find this information interesting and useful…

What are Smart Ceramics?

Most materials that we use in everyday life are 'dumb' or passive materials. We use them because of their mechanical or structural properties, that is their strength, toughness, hardness etc.. We do not expect the materials that our table is made out of to really do anything other than hold itself and perhaps our dinner off the floor! However, a new class of materials, functional materials, are now being used in everyday applications. These are a group of materials that are used not for their mechanical properties, but for other reasons, such as their magnetic, optical, electrical or thermal properties and smart materials (see box) are a group of functional materials.

The ceramics are probably the oldest group of materials. They include rocks and clays, cement, concrete, glass and precious gemstones. They are a group of materials that generally speaking are strong, particularly in compression and hard, they have high melting points, so can be used in hot environments and they are good electrical and thermal insulators. However, they tend to have poor toughness, that is they do not require the input of much energy to cause them to fracture and can be described as brittle materials, that is there is very little or no plastic deformation between their yield point and ultimate tensile strength. We have all experienced these detrimental properties first hand – when you drop a glass or plate on to the hard kitchen floor chances are it will shatter! Poor toughness and brittleness have not stopped ceramics from finding widespread applications in our everyday world. They form the basis of construction materials as they can withstand exposure to the weather, they are important as insulators in the transmission of electricity, they are commonly used in white wares (crockery and sanitary ware) as they are hard, durable and easy to keep clean and they are used in more hi-tech applications such as thermal shields where their excellent thermal insulation properties are crucial.

Ceramics however, have some useful functional properties too and smart ceramics can be incorporated in to larger systems as both actuators and sensors. Smart ceramics fall in to three categories, piezoelectric, pyroelectric and ferroelectric materials and the three are related as show in the Venn Diagram right.

Piezoelectric materials

The piezoelectric effect was first identified in 1880 by Pierre and Jacques Curie, brothers who did extensive research in to the magnetic and electrical properties of materials. They discovered that an electrical potential was generated when quartz crystals were compressed and in 1881 they also showed the reverse effect, i.e. if an electrical potential was put across a quartz crystal it would experience a shape

WHAT ARE SMART MATERIALS?

Smart materials are a group of materials that change in some way with a change in one aspect of their surrounding environment. Some smart materials change colour, others size or shape and some will experience a change in electrical resistance or even viscosity. This change can be associated with a change in temperature, UV light level, electric or magnetic field, or applied stress. No matter what the change is or the stimulus which causes it, smart materials have two things in common. Firstly, the change is completely reversible, as soon as the stimulus is removed the material will revert to its original state. Secondly, the change is an intrinsic property of the material, that is it happens because something inside the material is changing. This could be the atoms, molecules or particles changing position and changes in structure on a microscopic or even atomic level can manifest themselves as changes that are clearly visible with the naked eye.

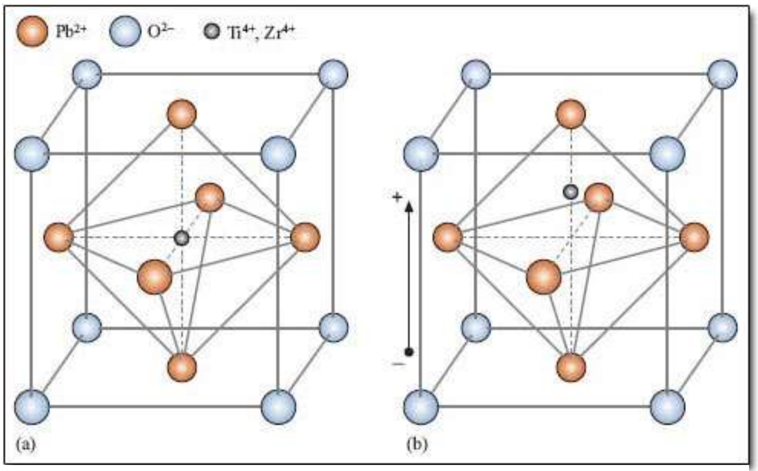
Commonly used smart materials include:

- Thermochromic polymers which change colour with a change in temperature. These are used in kettles that change colour as the water is heated, strip thermometers, colour changing bath toys, baby spoons and toothbrushes.
- Photochromic polymers are used for coatings on spectacle lenses which cause them to turn in to sunglasses outside on a sunny day. The structure of the coating is sensitive to the UV light level, when the level is low the coating is clear and non-coloured, but when exposed to higher levels of UV the structure of the coating changes and becomes transparent.
- Shape memory metals are a group of alloys that exhibit a change in shape when exposed to a change in temperature. The most commonly used shape memory metal is Nitinol, an alloy of nickel and titanium and it can be made to have a memory temperature anywhere between -100°C and +100°C simply by making the composition slightly more nickel or titanium rich. Nitinol has found applications in a wide range of areas from bone plates which contract on heating to pull the ends of a broken bone closer together (one-way shape memory) to artificial muscles for robotic limbs (two-way shape memory) and bendy spectacle frames which do not easily suffer from permanent deformation (superelastic effect).
- Quantum Tunnelling Composite (QTC) is a smart composite comprising finely divided nickel powder in a polymer matrix. The electrical resistance of this material varies linearly with applied pressure; in the absence of applied pressure it is a near perfect electrical insulator, however as pressure is applied the electrical resistance drops allowing a current to flow. QTC is now being used in textile-based applications for mp3 player controllers which are sewn in to the sleeves of garments and allow the wearer to control the music device without having to unzip the jacket and delve in to the pockets.
- Some smart materials are fluids rather than solids. Electro- and magneto-rheological fluids are liquids whose viscosity changes when an electrical or magnetic field is applied. The smart fluid comprises of a carrier liquid such as mineral or vegetable oil and a suspension of tiny particles which are susceptible to either an electrical or magnetic field. When a field is applied the particles in the carrier align and cause the liquid to become instantly solid. Magneto-rheological fluids can be used in damping and braking systems and for precision polishing.

change. They named this phenomenon piezoelectricity after the Greek word '*piezin*' which means to squeeze or press.

The piezoelectric effect can be seen in a number of natural materials such as tourmaline, topaz, cane sugar, and most notably quartz. In order to increase the piezoelectric effect man-made ceramics have been developed including barium titanate (the first piezoelectric man-made ceramic), lead titanate, potassium niobate, lithium tantalite and the most commonly used man-made ceramic, lead zirconate titanate or PZT. The crystals of these materials take on a perovskite structure, which is quite complex. The ideal piezoelectric material should be ionically bonded, that is the structure is made up of positively and negatively charged ions held together by electrostatic attraction, and contain ions that are free to move by a small amount (this motion must be small, if the ion were able to move by an unlimited amount the material would be an electrical conductor rather than an insulator). In the case of PZT the central titanium or zirconium ion is held within a cage of lead and oxygen atoms as shown below. However that central ion is able to move by a small amount when a field is applied, thus polarising the material as shown.

When an electrical field is applied to PZT the central ion moves, polarising the material and causing a shape change. This is known as the MOTOR EFFECT. If a stress is applied to the crystal this induces a strain in the lattice (i.e. the central atom moves) resulting in the generation of an electrical potential. This is known as the GENERATOR EFFECT.

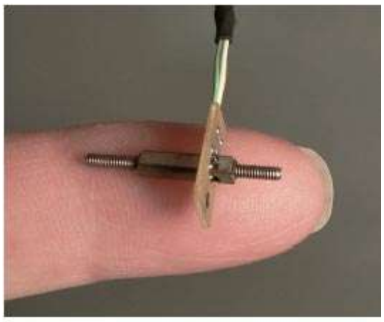


(a) crystal structure of PZT and (b) structure in presence of electrical field showing slight movement of central ion.

The earliest applications of the piezoelectric effect used quartz in lighters where pressing the button causes a hammer to hit a piece of quartz, thus changing its shape and generating a sufficiently high voltage to allow a current to flow across a small gap and ignite lighter fluid. The igniters on gas stoves work in the same way. Piezoelectric materials have found a range of other applications including:

- Sensors. Sensing applications make use of the generator effect in these materials, that is the shape change is used to generate a voltage. Piezoelectric sensors are used in microphones and guitar pick-ups where the shape of the crystal is changed by the vibrations of the sound waves, generating a changing field. Ultrasound machines also use piezoelectric crystals as actuators (to transmit the ultrasound in to the body) and sensors (to detect the returning signal). A crystal which acts both as an actuator and sensor is called a transducer. Piezoelectric transducers are also used for sonar applications, electric drums and car engine management systems. Other applications of piezoelectric sensors include monitoring power in high power applications such as industrial processing and medical treatment, monitoring sensitive chemical and biological systems and strain gauges attached to structures. These strain gauges can be used to detect earthquakes and set off alarm systems. Car air bag sensors are also piezoelectric. The impact causes a shape change in a piezoelectric crystal, thus producing a voltage which triggers release of the air bag. All this happens in a fraction of a second.

- Actuators. In piezoelectric materials tiny changes in the size of the crystal are associated with high voltages, this means that incredible accuracy can be achieved when placing objects with micrometer-precision. Piezoelectrics have therefore found widespread use as actuators (i.e. a voltage is applied to create movement – the motor effect). In piezoelectric loudspeakers voltages equating to the sound waves are converted to movement in a piezoelectric film or exciter. Piezoelectric motors offer an alternative to the stepper motor as they are very small and an applied voltage can be used to generate a shape change which causes an axle to rotate. Atomic force and scanning tunnelling microscopes make use of piezoelectric sensors to keep the sensing needle close to the probe. Piezoelectric materials are often used in inkjet printers to control the flow of ink from the inkjet head to the paper and finally in fuel injectors for high performance diesel engines for rail applications.



This 10-mm Squiggle motor can be used in mobile-phone autofocus cameras, optical zoom assemblies, and other small products.

- Piezoelectric motors are commonly used in digital cameras and camera phones in the auto-focus function to move the lens by small amounts.

- Piezoelectric crystals such as quartz are a used as a frequency standard. Quartz watches use the regular and stable vibration of tiny crystals to mark time.

- Piezoelectric crystals can be used in systems to reduce and damp out vibrations. One crystal behaves like a sensor to detect a vibration; the vibration of the crystal produces movement which is converted into a voltage. The reverse voltage is applied to another crystal which generates the opposite movement, thus damping out the vibration. Such systems can be used in skis, tennis racquets and cricket bats. It may also be possible to reduce noise in cars produced by the vibration of body parts using similar systems.

Pyroelectric materials

Pyroelectric materials produce an electrical potential with a change in temperature and again the phenomenon occurs because of a tiny change in structure. As the temperature increases or decreases the positively and negatively charged ions in the structure move slightly and the material becomes polarised thus producing and electrical potential. This phenomenon was first discovered in natural crystals such as quartz, but man-made ceramics are now more commonly used.

The most common application of pyroelectric materials is in intruder alarms which sense the heat of the persons body. The slight increase in the temperature of the sensor causes a shape change which generates a voltage and triggers and alarm. Pyroelectric materials can also be used in heat sensing thermal imaging cameras. The pyroelectric sensor detects the IR radiation produced by warm bodies to produce an image.

Ferroelectric materials

Ferroelectric materials are spontaneously polarised and the direction of polarisation can be switched by the application of an external field. The behaviour of these materials can be compared to ferromagnetic materials.

Ferroelectric materials are vital to today's electronics-led society as they can be used for electronic components such as capacitors and memory cells. The materials are used to make RAM for computers and radio frequency identity cards. These applications utilise a thin film of ferroelectric materials as these allow high field to be generated, to switch the polarity, with the application of only a moderate voltage.

Where can I find out more?

As with most topics, there is a wealth of information out there on the internet. I found these sources of information particularly useful as they used language which wasn't too technical.

www.piezoelectric.net

http://openlearn.open.ac.uk/mod/resource/view.php?id=257274

http://en.wikipedia.org articles on piezoelectricity, pyroelectricity and ferroelectricity

www.piezomaterials.com

www.azom.com articles on piezoelectric and ferroelectric materials.

If you would like to find out more about the National Physical Laboratory, where Dr Markys Cain works you can visit www.npl.co.uk.

Materials question - IS GRAPHITE A CERAMIC?

In this issue we will consider a question that was posed on the on the CAPT network, an e-mail group of all the Advancing Physics teachers. *Is Graphite a ceramic?*

What is a ceramic?

- ↳ Something that is made of clay and fired
- ↳ A material that is hard, brittle, thermal and electrical insulator, opaque, high melting point, good in compression *[this is the definition a pupil might give]*
- ↳ A material that is inorganic and non-metallic *[this true definition is not based on properties]*

What is graphite?

- ↳ Hard – what does this mean? See information box right.
- ↳ Brittle ✓
- ↳ Conducts electricity* – Ionic conductors are used in fuel cells and are ceramics
- ↳ Conducts heat* – ceramics are used for cooker hobs
- ↳ Opaque ✓
- ↳ High melting point ✓
- ↳ Good in compression ✓

* These are not actually defining properties of a ceramic. They are dependent on bonding.

Therefore:

- Based on the pupil definition graphite may be a ceramic.
- Based on the true non-property based definition graphite is a ceramic as it is not organic and not metallic.

Graphite is used in the following applications:

- Electrodes for the electrolysis of aluminium and for the generation of heat in the electric arc furnace for the production of steel.
- Neutron moderator in thermal nuclear reactors. The neutron moderator slows fast neutrons, typically travelling at 10% of the speed of light to thermal neutrons, travelling at a few kilometres per second. These thermal neutrons are capable of sustaining a nuclear chain reaction.
- Pencil 'lead'. Graphite has a structure made up of sheets of atoms which can easily slide across each other and be separated, thus leaving a mark on paper. For the same reason graphite can also be used as a lubricant to high temperatures.

In the 1920s a paper was published by the American Glass Society on the definition of ceramics: www.acers.org/acers/aboutceramics.asp

What is hardness?

Hardness can be defined in a number of ways but it is basically the resistance of a solid material to a shape change when a force is applied. Three types of hardness can be used:

- ***Scratch hardness*** is the resistance of a material to plastic deformation due to friction from a sharp object. Scratch hardness is often used in mineralogy where a harder material is used to penetrate a softer material. The Mohs Hardness scale ranks natural materials based on their ability to scratch and be scratched by each other, where 1 is the softest material and 10 is the hardest material.

1 Talc, 2 Gypsum, 3 Calcite, 4 Fluorite, 5 Apatite, 6 Orthoclase, 7 Quartz, 8 Topaz, 9 Corundum, 10 Diamond

On this scale graphite used in pencils has a hardness of 1 so it is a very soft material.

- ***Indentation hardness*** is the resistance of a material to plastic deformation due to a constant load from a sharp object. This is the most commonly used definition of hardness in materials engineering and a number of scales are available. Vickers hardness has a very wide range of values and is measured by pushing a pyramid-shaped diamond into the surface of a polished material using a known load (e.g. 5, 10 or 20 kg). The size of the indentation produced is measured and this correlates to a hardness value.

- ***Rebound hardness*** is measured as the height of bounce of a diamond tipped hammer dropped on to the surface of the material from a fixed height.

Reflections after a year in post...

I write this after just having helped with the 4-day Mining and Minerals "taster" course run by the Smallpeice Trust at Leeds University (where I work 3 days a week in the Mining Programme). There has also been a course at Camborne School of Mines (Exeter University), and between them, over 60 young people got to see first hand what a career in the minerals industry can look like through a number of site visits and informal lectures. The young people were enthusiastic and definitely excited by the global opportunities and the excellent salaries on offer.

Earlier in July, I ran another "taster" course at Leeds, but this time it was specifically for A-level geology students. We visited a limestone quarry, a sand & gravel quarry and the National Coal Mining Museum (a deep mine near Wakefield). Again, the feedback was excellent and we hope a number will be applying for places next year.

Please do encourage your students to think about a Mining or applied geology degree. At the moment, every graduate is a guaranteed a job in the industry if they want it, and I don't think its going to change much in the next 10 years, as most of the demands is driven by China & India. Entry requirements at Leeds are BBB including two from Maths, Physics, Chemistry and Geology. I think the requirements for Camborne are very similar.

I have thoroughly enjoyed working for the Schools Affiliate Scheme for a year now. Covering for Diane's maternity leave earlier in the year certainly made me extend my knowledge on the materials side, especially Smart Materials, which I love taking about. It's great being able to follow a metal all the way through from digging it out of the ground to some really ingenious applications (watch out for the new SAS resource!).

This year has also seen my first visit to the ASE conference, which was great fun, as well as number of other events. Wherever there are groups of science teachers gathered together, we want to be there, so if you know of any, please do invite us!

The best bit, however, has been the school visits. From Truro to Aberdeen, from Westcliff (my old school) to Penrith, it's been great to support the teaching of materials, minerals and mining in the curriculum. The Crash Helmets for Eggs activity always offers high drama at the test stage, and some really creative solutions.

As I look to the coming year, I hope to focus more on the Geology lessons and develop additional material to offer to schools. I look forward to seeing some of you in the coming year when I visit.

Niobium – origin, extraction and processing.

Niobium is never found as a free element but occurs in a number of minerals, including:

columbite	($(Fe,Mn)(Nb,Ta)_2O_6$),
pyrochlore	($(Na,Ca)_2Nb_2O_6(OH,F)$), and
euxenite	($(Y,Ca,Ce,U,Th)(Nb,Ta,Ti)_2O_6$).

Pyrochlore is the main commercial source of niobium and large deposits have been found associated with carbonatites (carbon-silicate igneous rocks). It can also be found in a wide range of pegmatites (very course-grained, intrusive igneous rocks with crystals more than 20mm).

Carbonatites are rare, peculiar igneous rocks formed by unusual processes and from unusual source rocks. They are peculiar because they comprise more than 50% by volume of carbonate minerals (including calcite ($CaCO_3$) and dolomite ($(Ca,Mg)CO_3$)), and less than 10% SiO_2. Carbonatites may be confused with marble (metamorphosed limestone, which is mainly $CaCO_3$) and indeed for many years they were considered as marbles as no-one thought you could get igneous rocks with such a strange, carbonate-rich mineralogy.

Niobium output in 2007, shown in percentage of top producer (Brazil – 40,000 t) (from Wikipedia)

Brazil and Canada are the major producers of niobium mineral concentrates and extensive ore reserves also exist in Nigeria, Democratic Republic of Congo, and in Russia. The world's largest deposit is part of the Barreiro Carbonatite Complex near Araxá in Brazil. This was formed about 90 million years ago when an intrusion about 5km in diameter forced its way up into quartzites and schists, causing the rock above to dome and fracture. Subsequent erosion has now revealed these igneous rocks on the surface.

Surface mining a niobium deposit near Araxá, Brazil.

The Araxá deposit has about 450 million tonnes of ore, which is enough for around 500 years production! The primary ore has a grade (content by weight) of Nb_2O_5 ranging from 1.5% to 8%, but it is currently the "weathered" material (called the residual ore) near the surface that is being mined and this has a mean concentration of 2.5% Nb_2O_5. Because the mine is in an area of high temperature and rainfall, this "weathered" layer can be up to 250m thick!

A Caterpillar D8 dozer – used on the Araxá mine.

Mining is fairly straightforward, with no blasting necessary. Bulldozers (Caterpillar D8s) are used to push the material into piles that are then loaded by large shovels into dump trucks. These feed a 3.2 km conveyor which takes the material to the processing plant.

Not much crushing is needed, because the material is already degraded and disaggregated (the minerals are already separated), but grinding is required to get the material to less than 100 microns. Any magnetite that may be present is removed using magnetic separators and then the extremely fine material called slimes (< 5 microns) is removed as this has an adverse effect on the next stage which is flotation.

Froth flotation, with ore grains sticking to the bubbles and flowing over the side.

Froth flotation involves passing the ground-up material through vats (or cells) of acidified water with a number of chemicals added. When they are in the cells, bubbles are generated and the metal bearing minerals stick to the bubble surfaces because they are hydrophobic (they are repelled by water). The remaining waste material is hydrophilic (attracted by water), so is happy to stay in the cell and accumulate in the bottom. At the top of the cell, the bubbles with ore minerals attached overflow and are collected. After going through a series of cells, the material is then thickened and filtered to reduce the moisture content. This concentrate is approximately 60% Nb_2O_5.

Electron beam furnace (not all furnaces are big and dirty!)

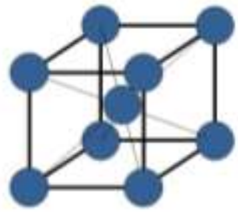
This concentrate then needs to be refined, and there are a number of different ways this can be done, depending on the ultimate product required. The mine at Araxá produces high grade ferro- and nickel-niobium, as well as niobium metal ingots, using a process known as electron beam refining. Other possible methods include the aluminothermic reduction process and reduction in an electric arc furnace.

If you would like to find out more, some useful resources include:

www.cbmm.com.br/english/index.html
www.tanb.org/niobium1.html
www.niocan.com

Niobium

- Niobium sits in the second transition series of metals directly below vanadium and above tantalum. Its chemical properties are very similar to those of tantalum and for many years the two elements were indistinguishable.



- It has atomic number 41, and other properties include a density of $8.57 g.cm^{-3}$, melting point 2477°C and boiling point 4744°C
- Niobium is a grey metallic ductile metal that has a body centred cubic crystal structure at room temperature.
- The discovery and naming of niobium has raised controversy over the years. In 1801 an Englishman, Charles Hatchett, isolated a new element from an ore called Columbite, which he obtained from the British Museum after it had been donated by John Winthrop, the Governor of Connecticut, in the 1740s. He named the new metal Columium, after the ore from which it originated. For many years chemists argued that this new element was in fact tantalum, which had been discovered some years earlier. This confusion is understandable as niobium and tantalum have very similar properties and are found together in Columbite. In 1846 Heinrich Rose re-discovered the element and named it niobium after Niobe, the daughter of Tantalus in Greek mythology. For a hundred years or so element 41 was known as columbium in North America and niobium in Europe. In 1950 the International Union of Pure and Applied Chemistry (IUPAC) came to a compromise: element 41 would be known as niobium and element 74 would be known as tungsten (this was the name used in North America, it was known as Wolfram in Europe). However, not all producers, manufactures and supplier have adhered to this ruling, many American companies still refer to niobium as columbium.

- Niobium begins to oxidise above 200°C so processing above this temperature must be done under a protective atmosphere. However anodising the material to control the oxidation leads to the development of a wide array of colours.
- Niobium is becoming an increasingly popular choice for making jewellery as it does not react with the human body, is easy to shape and can be anodised to produce interesting colours.

- Probably the most important use of niobium is as an alloying addition to High Strength Low Alloy (HSLA) steels. Niobium and titanium are added to HSLA steels in quantities of a few tens of parts per million where they are used to control the development of the microstructure in the steel during processing. These two metals are powerful grain refiners and produce steels that have a small grain size, which is beneficial to both strength and toughness, particularly at low temperatures. Uses of HSLA steels include off-shore oil platforms and the pipelines that carry oil and gas from these platforms to refineries on-shore. Niobium is added to steels in the form of ferro-niobium, a brittle intermetallic compound comprising around 63% niobium by weight and approximately 30% iron with the remaining 7% a mixture of phosphorus, sulphur, carbon, lead, aluminium, silicon and titanium.
- High purity ferro-niobium and nickel-niobium are used in iron- and nickel- based superalloys for aerospace and rocket applications.
- Niobium can be used in medical components such as pacemaker cases. When niobium is treated with sodium hydroxide a porous surface layer is produced which aids osseointegration (i.e. bone can grow on to the surface of the component more easily).
- Niobium has the highest critical temperature of all the elemental metals. It becomes a superconductor at a temperature of 9.3K